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Original Communication

# Correlation of foot length with height and weight in school age children

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**Abstract**

Even though the forensic value of the correlation between foot length and human height and weight has been studied, there is a lack of studies regarding this subject in school age children. The aim of this study is to evaluate this relationship in a large sample of juveniles in a European country (Greece). The sample of the study consisted of 5093 children (average age: $11.47 \pm 2.71$ years), who were examined during school period from 1996 to 2005. The Harris–Beath Mat for footprinting was the device used for measuring foot length. Statistical analysis included univariate and multivariate linear regression models. All statistical models were found to be significant and indicated that both right and left foot length were independent predictors of either height or weight. From all models fitted, the model having the greater predictive value was described by the formula: height (cm) = $34.113 + 3.716 \times$ (right foot length (cm)) + 1.558 (if girl) + $2.499 \times$ (age(years)), $R^2 = 0.852$. It was also found that the models which contained right rather than left foot length as an explanatory variable predicted more accurately both height and weight. The results of this study suggest that foot length can estimate the stature and weight of a juvenile, especially after adjusting for age and sex.


*Keywords:* Foot; Length; Height; Weight; Children; Forensic

## 1. Introduction

The anatomic parameters of human body such as height, weight and the size of some specific parts of it have been thoroughly studied in literature for various purposes.[1–10] However, it seems that the correlation between some of those parameters in order to estimate human height and weight has not been studied in particular.

The development of the human foot and the age in which its size approaches that of the mature human skeleton constitute points of interest. The acquisition of the mean values and of the standard deviations of those variables might be useful in treating surgical pathologies such as talipes equinavarus, flat foot or varus metatarsal. and other familiar or acquired abnormalities in a way that it can help making a treatment decision.[6]

The rise of criminality in modern societies – involving children very often – is a fact.[11] As a result, the elaboration of studies which can help the criminologists' works becomes an essential priority. The search for many lost children creates a new challenge in modern criminology. Most of the times, the authorities are obliged to work with nothing more than a foot imprint as evidence.

The usage of specific anatomic parameters such as height, weight and foot length, which can be easily accessed by many health authorities, might lead – with the help of proper statistical analysis – to the production of linear equations which could calculate an estimated value for either the height or the weight, should the foot length be already known.[4,7,8,12–14]

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The amount of modern studies concerning the forensic value of measurements of basic anthropological dimensions and especially the correlation between the foot length and the human height and weight is not impressive.[1,4,7,12–15] The interesting detail which is stressed in the above publications is the simplicity of foot length as criminological evidence, the easiness of measuring as well as the satisfactory precision with which the human body weight and height are estimated. At the same time, other publications connect the length of foot bones with weight and height, thus helping in the identification of dead due to mass destructions,[2,16–18] while other studies underline the forensic value of clothes and especially footwear, as they can help in the identification of individuals in criminological issues.[7,12,13,19] The difficulties in the criminological work because of the bad situation of the body and the absence of fingerprints when the death is violent can be overcome by the measurement of foot length.[13] The correlation of foot length with weight and height seems to exist even in dead foetuses, thus estimating with satisfactory precision embryonic body dimensions, even the age of the foetus.[5]

The absence of studies concerning the forensic value of foot length in juveniles in a large sample from a European country led us to conduct this study the aim of which is to estimate height and weight in school age children using at least a foot imprint.

## 2. Methods

### 2.1. The team of participating examiners

The team of the participating examiners consisted of the research team and of the "Thriassio" general hospital health visitors department. The teachers of the children may contribute to that last process occasionally, depending on the situation. The participation of female health visitors facilitated the participation of older girls. The health visitors also helped the younger pupils who couldn't self serve.

### 2.2. The license

The Orthopaedics department required permission from the administrative council of the hospital, which acted officially in order to acquire permission from the ministry of education. The last was necessary in order to enter and work in the schools.

### 2.3. The material

The material consisted of two parts: The animate (students of the schools) and the inanimate (the protocol which was used, the application and approval form signed by the parents, the letter to the parents for re-examination of their children, the tools such as the height and weight measurer and the Harris–Beath mat for foot printing.[19,20]) All the Helsinki declarations (1975) had been considered. The application and approval agreement printed form was delivered two days earlier to the students, in order to return it signed by their parents.

The stature was measured using a metal scale while the weight measurer was an electronic one, accurate to within 500 g. Both instruments (metal scale and electronic weight measurer) carried the CE[21] mark, meeting all the essential health and safety requirements set out in European Union Directives. The students wore light clothing when they were measured. The metric system which was used was the European standard with increments in cm and kg, respectively. Foot length was the maximum distance between the most anterior and posterior projecting part of the footprint on the Harris–Beath Mat and was measured with a sliding caliper. Both of the feet were measured in all of the participants.

The schools that the investigation team was authorised to visit were 90 primary and 36 high schools with a total of 21,234 students in various municipalities near Thriassio Hospital, Elefsina, Attica, Greece. This an urban, industrialized suburb not far away (~20 km) from Athens.

The sample size was assessed prior to the start of the study by power analysis which showed that a number of 4203 participants would be adequate to detect two-sided mean differences of 0.5% in foot length and could achieve statistical power 90% at a probability level of 0.05. In addition, the authors increased this number by 25% to a total of 5254 in order to counter for potential low response. The sample should also follow the age and sex distribution according to national census,[22] in order to be representative of the population studied.

The students were examined during school period (September to May) from 1996 to 2005. The presence of the teachers was very useful, in order for the study procedure to be successful. The examination rooms were comfortable, illuminated, clean and heated classrooms, with enough chairs and tables for the students and the examiners. Curtains were placed in order to protect the students from indiscrete colleagues.

### 2.4. The data processing

Two different assistants performed height, weight and (right and left) foot length measurements. In order to assess the intra- and inter- observer error of measurements, the first 100 children who participated to the study were examined by the two different assistants in the same day. The same children were re-examined two days after the first measurement by the same assistants. The coefficient of reliability ($R$) was then calculated using the formula: $R = 1 - \left(\frac{\left(\frac{\sum D^2}{2N}\right)}{SD^2}\right)$, where $D$ is the difference between the two measurements (of the same examiner for calculating intra-observer reliability, or of the two examiners for calculating inter-observer reliability), $N$ is the sample size (100 in our case) and SD is the standard deviation of all measurements. All coefficients which tested the intra- and inter-

observer reliability for the three aforementioned anthropometric characteristics exceeded 0.95, securing the reliability of the measurements. The same procedure was performed four times during the study and the results were similar. The normality of the data was verified with the Shapiro–Wilk test for normal data. The statistical analysis included three steps; firstly, a Student's $t$-test was conducted in order to compare the independent variables (age, right foot length, left foot length) as well as the dependent variables (height, weight) between the two genders. Secondly, the magnitude of the linear correlation between the independent and the dependent variables was estimated by calculating the Pearson $r$ correlation coefficient. Thirdly, four univariate (2 dependent $\times$ 2 main independent variables) and four multivariate regression models (2 for the two dependent variables $\times$ 2 main independent variables, adjusting for age and sex) were constructed. The overall significance of the model was based on the calculation of $F$ statistic, whereas, the $t$ statistic was estimated for each variable added in the multivariate model. The best model was chosen according to the values of $R^2$ statistic. $R^2$ is the proportion of variation in the dependent variable predicted by the independent variable(s). The $R^2$ is used to compare the linear regression models which have the same amount of independent variables, whereas, the adjusted $R^2$ is used to compare the explanatory value of regression models with the same dependent and different amount of independent variables. After the main analysis was performed, a reference sample of 51 (1% of our main sample) was retained from the same population, keeping the same age and sex distribution in order to test the reliability of the formulae produced. Regression functions using the characteristics of those individuals were separately calculated producing estimated weight and height. The mean estimated characteristics were compared with the real ones using Student's $t$-test. All statistics were considered significant if $p$-value was less than 0.05.

The Data were analyzed using STATA$^{\text{trade}}$ (Version 9.0, Stata Corporation, College station, TX 77845, 800-782-8272).

## 3. Results

The sample of the study consisted of 5093 children (2535 boys, 49.77%, 2558 girls, 50.23%). The response ratio was 96.93%. The average age of the sample was $11.47 \pm 2.71$ years.

The descriptive statistics such as the means and standard deviations for the dependent variables (height, weight) as well as the independent variables (age, right foot length, left foot length) are classified by sex and are shown in Table 1. According to the results, a significant difference was found in right and left foot length between the two genders. The age, height and weight did not differ significantly.

The simple bivariate Pearson $r$ correlations between the dependent and independent variables are shown for both genders in Table 2. All coefficients were statistically significant ($p < 0.001$) and indicated a linear relationship between the variables. The relationships described were rather strong, not falling below 0.733. The relationship between right and left foot length and height was stronger in boys than in girls (0.903, 0.898 vs. 0.855, 0.856, respectively). The above difference was also found regarding the two main independent variables and weight (0.818, 0.808 vs. 0.756, 0.757, respectively).

The scatter-plot matrix describing all possible relationships between the independent and dependent variables for each gender is shown in Fig. 1. The linear relationship which was calculated using Pearson $r$ in Table 2 is described graphically in those matrices. Four univariate linear regression models were constructed. The dependent variables were height and weight, whereas, the independent variables were right and left foot length. All models were found to be statistically significant ($F$-test $p$-value $< 0.001$). The results of the univariate linear regression models are shown in Table 3.

The formulae which were produced after the univariate linear regression modelling in order to estimate height and weight when sex and age are unknown are the following:

Height:

$$\begin{aligned}\text{Height (cm)} &= 17.369 + 5.879 \times (\text{right foot length (cm)}),\\ &= 17.592 + 5.861 \times (\text{light foot length (cm)}).\end{aligned}$$

Weight:

$$\begin{aligned}\text{Weight (kg)} &= -71.142 + 5.259 \times (\text{right foot length (cm)}),\\ &= -70.385 + 5.217 \times (\text{left foot length (cm)}).\end{aligned}$$

In order to estimate height and weight using the right and left foot length adjusting for sex and age, four new multivariate linear regression models were constructed. The results of the multivariate modelling are shown in Table 4. The formulae produced by multivariate linear regression modelling when the sex and age of the child are known are:

Height:

Boys:

$$\begin{aligned}\text{Height (cm)} &= 34.113 + 3.716 \times \text{right foot length (cm)}\\ &\quad + 2.499 \times (\text{age (years)})\\ &= 33.869 + 3.689 \times \text{left foot length (cm)})\\ &\quad + 2.533 \times (\text{age (years)}).\end{aligned}$$

Girls:

$$\begin{aligned}\text{Height (cm)} &= 34.113 + 3.716 \times (\text{right foot length (cm)})\\ &\quad + 1.558 + 2.499 \times (\text{age (years)})\\ &= 33.869 + 3.689 \times (\text{left foot length (cm)})\\ &\quad + 1.774 + 2.533 \times (\text{age (years)}).\end{aligned}$$

Table 1
Descriptive statistics of the main characteristics of the study and comparisons between sexes

| | Sex | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Boys | | | | Girls | | | | |
| | Mean | SD | Min | Max | Mean | SD | Min | Max | *p*-Value |
| Age (years) | 11.37 | 2.69 | 5.49 | 20.06 | 11.36 | 2.73 | 5.99 | 18.46 | 0.989 |
| Height (cm) | 147.44 | 16.78 | 105.00 | 202.00 | 146.80 | 14.49 | 107.00 | 183.00 | 0.145 |
| Weight (Kg) | 45.04 | 16.77 | 17.00 | 119.00 | 44.79 | 14.44 | 16.00 | 109.00 | 0.573 |
| Left foot length (cm) | 22.50 | 2.54 | 16.00 | 29.00 | 21.71 | 2.01 | 15.00 | 29.00 | <0.001 |
| Right foot length (cm) | 22.43 | 2.56 | 15.00 | 28.00 | 21.71 | 2.01 | 15.00 | 27.00 | <0.001 |
| Age categories | | | *N* | Percentage | | | *N* | Percentage | |
| 4–6 Years | | | 140 | 5.52 | | | 135 | 5.28 | 0.062 |
| 7–9 Years | | | 685 | 27.02 | | | 630 | 24.63 | |
| 10–12 Years | | | 943 | 37.20 | | | 942 | 36.83 | |
| 13–15 Years | | | 670 | 26.43 | | | 721 | 28.19 | |
| 16–18 Years | | | 97 | 3.83 | | | 130 | 5.08 | |
| Total | | | 2535 | 100.00 | | | 2558 | 100.00 | |

Table 2
Simple bivariate correlations between dependent variables (height and weight) and independent variables (age, right and left foot length) by sex

| | | Boys | | Girls | |
|---|---|---|---|---|---|
| | | Height (cm) | Weight (Kg) | Height (cm) | Weight (Kg) |
| Age (years) | Pearson correlation | 0.877 | 0.766 | 0.841 | 0.733 |
| | *p*-Value | <0.001 | <0.001 | <0.001 | <0.001 |
| Left foot length (cm) | Pearson correlation | 0.898 | 0.808 | 0.856 | 0.757 |
| | *p*-Value | <0.001 | <0.001 | <0.001 | <0.001 |
| Right foot length (cm) | Pearson correlation | 0.903 | 0.818 | 0.855 | 0.756 |
| | *p*-Value | <0.001 | <0.001 | <0.001 | <0.001 |

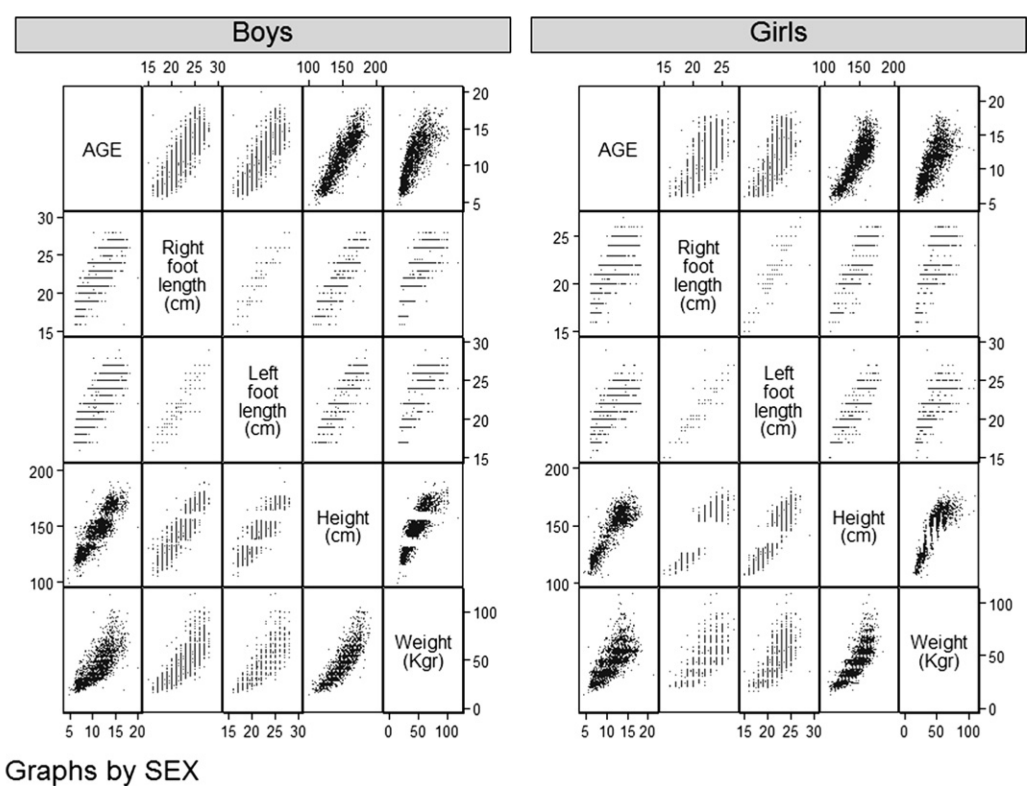


Fig. 1. Scatter-plot matrix representing the relationships between the dependent variables (height, weight) and the explanatory variables (right and left foot length, age) for both sexes.

Table 3
Four univariate linear regression models

| Height (cm) | Unstandardized coefficient $b$ | Coef. std. error | $t$ | $p$-Value | (95% Conf. interval) | | $R^2_{adj}$ | SEE[a] |
|---|---|---|---|---|---|---|---|---|
| Right foot length | 5.879 | 0.046 | 128.490 | <0.001 | 5.790 | 5.969 | 0.765 | 7.603 |
| Constant | 17.369 | 1.015 | 17.110 | <0.001 | 15.379 | 19.360 | ~ | |
| Left foot length | 5.861 | 0.047 | 125.940 | <0.001 | 5.769 | 5.952 | 0.757 | 7.721 |
| Constant | 17.592 | 1.034 | 17.010 | <0.001 | 15.565 | 19.620 | | |
| Weight (kg) | | | | | | | | |
| Right foot length | 5.259 | 0.059 | 89.880 | <0.001 | 5.144 | 5.373 | 0.614 | 9.720 |
| Constant | −71.142 | 1.298 | −54.790 | <0.001 | −73.688 | −68.597 | | |
| Left foot length | 5.217 | 0.059 | 87.690 | <0.001 | 5.100 | 5.333 | 0.602 | 9.867 |
| Constant | −70.385 | 1.322 | −53.240 | <0.001 | −72.977 | −67.793 | | |

Height and weight are the dependent variables and right and left foot length are the independent variables.
[a] SEE stands for standard error of the estimate.

Table 4
Four multivariate linear regression models

| Height (cm) | Unstandardized coefficient $b$ | Std. error | $t$ | $p$-Value | [95% Conf. interval] | | $R^2_{adj}$ | SEE[a] |
|---|---|---|---|---|---|---|---|---|
| Right foot length | 3.716 | 0.058 | 63.590 | <0.001 | 3.601 | 3.831 | 0.852 | 6.028 |
| Girls vs. boys | 1.558 | 0.177 | 8.830 | <0.001 | 1.212 | 1.904 | | |
| Age | 2.499 | 0.050 | 50.320 | <0.001 | 2.402 | 2.596 | | |
| Constant | 34.113 | 1.021 | 33.400 | <0.001 | 32.110 | 36.115 | | |
| Left foot length | 3.689 | 0.059 | 62.780 | <0.001 | 3.574 | 3.805 | 0.851 | 6.062 |
| Girls vs. boys | 1.774 | 0.179 | 9.930 | <0.001 | 1.424 | 2.124 | | |
| Age | 2.533 | 0.050 | 50.920 | <0.001 | 2.435 | 2.630 | | |
| Constant | 33.869 | 1.037 | 32.670 | <0.001 | 31.836 | 35.901 | | |
| Weight (kg) | | | | | | | | |
| Right foot length | 3.614 | 0.087 | 41.570 | <0.001 | 3.444 | 3.784 | 0.671 | 8.967 |
| Girls vs. boys | 1.994 | 0.263 | 7.600 | <0.001 | 1.480 | 2.509 | | |
| Age | 1.930 | 0.074 | 26.130 | <0.001 | 1.785 | 2.075 | | |
| Constant | −59.973 | 1.520 | −39.460 | <0.001 | −62.952 | −56.993 | | |
| Left foot length | 3.526 | 0.088 | 40.220 | <0.001 | 3.354 | 3.697 | 0.665 | 9.041 |
| Girls vs. boys | 2.146 | 0.266 | 8.060 | <0.001 | 1.624 | 2.668 | | |
| Age | 2.004 | 0.074 | 27.020 | <0.001 | 1.859 | 2.149 | | |
| Constant | −59.212 | 1.547 | −38.280 | <0.001 | −62.244 | −56.179 | | |

Height and weight are the dependent variables, whereas, right and left foot length, sex and age are the independent variables.
[a] SEE stands for standard error of the estimate.

Weight:

Boys:

$$\begin{aligned}\text{Weight (kg)} &= -59.973 + 3.614 \times (\text{right foot length (cm)}) \\ &\quad + 1.930 \times (\text{age (years)}) \\ &= -59.212 + 3.526 \times (\text{left foot length (cm)}) \\ &\quad + 2.004 \times (\text{age (years)}).\end{aligned}$$

Girls:

$$\begin{aligned}\text{Weight (kg)} &= -59.973 + 3.614 \times (\text{right foot length (cm)}) \\ &\quad + 1.994 + 1.930 \times (\text{age (years)}) \\ &= -59.212 + 3.526 \times (\text{left foot length (cm)}) \\ &\quad + 2.146 + 2.004 \times (\text{age (years)}).\end{aligned}$$

Comparing the univariate and multivariate models in Tables 3 and 4, it is obvious that the $R^2$ values are lower in univariate than in multivariate models. Such a result makes sense, since the more independent variables we have which contribute significantly to the model, the more accurately we predict the dependent variable. However, the $R^2_{adj}$ values in the univariate models for height are rather satisfactory (~75%) compared to the values in the multivariate models (~85%), where we adjust for sex and age. This result justifies our choice to construct univariate models in association with the forensic background which will be discussed later. After the application of the formulae presented in our reference sample, no statistically significant difference was found between estimated and real characteristics ($145.33 \pm 16.78$ vs. $146.39 \pm 18.23$, estimated vs. real height, respectively, $p = 0.706$ and $44.82 \pm 17.29$ vs. $45.91 \pm 17.25$, $p = 0.751$, estimated vs. real weight, respectively).

## 4. Discussion

This study indicates a correlation between right and left foot length and height and weight in school age children of

an urban area in Greece. This study underlines this relation and quantifies it as a linear equation formula. The determination of height and weight by using a footprint as evidence from a crime scene can be extremely useful to forensic scientists and criminologists in search of a lost child not only because a suspect or – more often in children – a victim can be indicated but also because an attestation can be supported.[7,12]

According to our findings, a significant relationship between height, weight and foot length was found, either regardless or adjusting for sex and age. The large size of the sample adds to the power of the analysis and makes our study the largest of its kind in this age group. Other authors have also written on this subject but never in school age children.[7,8,12,13]

Even though the results of our study suggest the linear relationship between foot length and stature, genetic, nutritional, environmental and behavioral factors play also a substantial role.[23,24]

Bavdekar et al. and Ashizawa et al. found a stronger relationship between foot length and weight in Indian children up to two years.[25,26] This difference might exist due to different age, nutrition patterns and environment.

The different growth pattern in boys and girls due to hormonal reasons results to a different skeletal maturity during adolescence.[27,28] Girls show a higher growth rate between 10 and 15 years old, whereas, boys follow after 3–4 years. This fact coincides with the results of our study, since either the left or right foot length differ significantly between boys and girls leading us to the construction of a multivariate model adjusting for sex.

The characteristics of our sample differed from other studies, mainly because of the different age of our sample.[7,8,12,13] Therefore, any comparisons regarding the regression formulae with those studies might be arbitrary. The relationship between right and left foot length and height was stronger compared to weight ($R^2 = 0.851$, 0.852 vs. 0.671, 0.665).

Although the adjusted $R^2$ values for these models clearly reflect a strong relationship between foot/boot length and stature, individual 95% prediction limits for even the best models are $\pm 86$ mm (3.4 in.). This suggests that models estimating stature from foot/shoe-prints may be useful in the development of subject descriptions early in a case but, because of their imprecision, may not always be helpful in excluding individual suspects from consideration.

Not only the adjusted $R^2$ values for the multivariate models indicate a significant relationship between foot length and height and weight but the best individual 95% prediction for height may vary for $\pm 6.028$ cm as it is derived from the standard error of the estimate (SEE) shown in Table 4. Even though this variance is better than those described in other studies,[12] it is still big enough not to be useful during a trial for example. However, it can be helpful during the initial investigation of a case from the police authorities.

Based on the same results, it is evident that the models which contain foot length, age and sex predict better the height and weight than the univariate models containing only foot length. It should be stressed, however, that the construction of univariate linear regression models was not an unjustified choice. The sample of that study contained other variables which could contribute to a more descriptive linear regression model. Such variables were parents' weight and height. The reason that those variables were not used was the specific aim of that study. The aim of this study was not just to describe somatometric characteristics given all the candidate independent variables for a paediatric research for example. Rather, it was mainly forensic because evidence from a crime scene may be scarce, for example only a footprint.

All in all, prediction of body height and weight in children from various crime scene evidence has serious prospect for forensic science. In our study, it is shown that even a single clue like a footprint can predict the stature and weight of a child with satisfactory accuracy. The international literature regarding this subject is rather limited, at least in this age group. This study adds new data concerning this sensitive social group.

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